

Carbon sequestration for everybody: decrease atmospheric carbon dioxide, earn money and improve the soil

Folke Günther
Holon Ecosystem Consultants
Lund, Sweden

<http://www.holon.se/folke>
folke@holon.se

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Summary:

The easiest way to sequester atmospheric carbon dioxide is to convert plant biomass into charcoal and bury it in agricultural land. Doing this will open a new way for farmers and laymen to earn money (from carbon sequestration funds) and improve land fertility. It is also a way to avoid nutrient loss from land to sea.

Key words:

biodiesel, biomass conversion, carbon sequestration, carbon sequestration fund, charcoal, industrial hemp, landscape improvement, nutrient adsorption, pyrolysis, soil improvement, soil microlife

Foreword

The main threat to the survival of mankind is not her ruthlessness, because that is certainly not uncommon in biological systems. The main threat is that she is virtually useless (or even harmful) to her support systems. Such organisms will sooner or later be eradicated.

Practically all organisms have a function in increasing the exergy consumption capacity of the system they are a part of, however mean, ugly, harmful or awkward they seem to us. Because it is better for the system to have them there, than not having them, they have survived.

This article aims at pointing out a method that diminishes a major recent threat, global warming from the increased carbon dioxide content of the atmosphere. Naturally, global warming may have many other reasons that may be both identifiable and remediable, but I focus on the special problem of carbon dioxide, because the remedy for that doesn't need an advanced technical improvement, just an adaptation of the system that has caused the problems. Furthermore, using this remedy at a large scale will also have benefits to our support system.

Lund, January 9, 2007
Folke Günther

Introduction

In 1542 Fransico de Orellana and a group of about 55 conquistadors was sent out on a rescue expedition to find food down the Napo River (one of the upper tributaries of the Amazon River, east of Quito). Following the Napo River didn't lead to substantial findings of food for the group that was to be rescued, and Orellana decided to follow the Amazon River downstream instead of going back upstream.¹ However, the Amazon River was very densely populated with 'very large settlements' 'with each village no more than a crossbow shot' from the next, and the conquistadors were fiercely attacked. According to the account of the group, the riverbanks practically bristled with armed warriors.

Few believed Orellana when the remnants of the expedition finally returned to Portugal, although he was recognized as the discoverer of the Amazon area and appointed governor over Amazonas. His stories of the rich native population actually gave rise to the tales about El Dorado, the city of gold. However, when explorers about eighty years later returned to the area, they found no signs of the alleged large indigenous cities, just jungle. Furthermore, in the 1950s, when the Smithsonian researchers Meggers and Evans visited the area, they concluded that Amazonia is a region with 'such intractably poor soils that it can not provide the agricultural base necessary for any larger population'².

This was the situation in the 70-ies and 80-ies when the demand for agricultural land and land reforms increased the pressure on the Amazonian rain forest. At that time, however, it became understood that only the pristine rain forest area was creating such an efficient ecosystem that the biomass kept nearly all nutrients and organic matter. The meagre soil under it is called an *oxisol*, which typically is very poor³. It contains few nutrients and little



Figure 1 The oxisol, a 'normal' rain forest soil. Photo Julie Major

organic matter. When used for agriculture, the leakage of nutrients is large, and the crops it creates are very meagre.

Terra preta

However, some of the soils in the Amazonian area are certainly not of this type. One is a blackish soil that keeps nutrients well and produces good crops. It is called *Terra preta* or *Terra preta do Indio*, which indicates that it is an *anthrosol*, i.e. a soil developed by human interaction. The Terra Preta soil is not an exclusive Amazonian phenomenon. It also occurs in other regions of South America such as Ecuador and Peru but also in Western Africa (Benin, Liberia) and in the savannas of South Africa⁴. An interesting fact is that, in Amazonia, the Terra preta soil mainly occurs on the places where Francisco de Orellana claimed that there were dense native populations!

Slash and char

Brazilian farmers have practiced a 'modern' form⁵ of 'slash and burn' techniques for some decades in the oxisol areas, reducing large swathes of rainforest to ash in order to uncover new ground for agriculture. The uncovered soil only yields a few years, normally less than five, and the crops it yields are very poor because the soil is completely exhausted in the end. After this period, the land has to be abandoned.

However, the native, pre-Columbian Indians of the Amazon River area developed the "slash and char" technique⁶. This entails cutting down a portion of the rainforest, but instead of clearing the area with unregulated fire, the cut trees are covered with straw, soil, turf, leafy vegetation or any other material that will choke the fire. After the incomplete burning, a large part of the original biomass is left behind as charcoal. Charcoal retains the majority of the nutrients and works as a 'reef' for the micro-organisms. When the charcoal is mixed with the underlying soil and nutrient rich waste, Terra Preta is created, one of the most fertile soils known in the world. Not only years, but centuries of high yields are attained with this type of cultivation.

It is easy to understand the advantages of this system. Imagine you are equipped with only stone-axes or some similar tools. Cutting down a rainforest to renew your food production area every fifth year is basically impossible. It is much better if you can develop a growing method that keeps your agricultural land intact and fertile for hundreds, or thousands, of years⁷.

Thus, the existence of the vast areas of Terra preta in the Amazon River region verifies Orellana's statement of the dense populations of native Indians living there.

It also gives us a clue on how we can fight what is currently considered one of the major threats to our civilisation; the carbon dioxide increase of the atmosphere.



Figure 2 An anthrosol, *Terra preta* from the same region as the oxisol on Figure 1. Photo Julie Major



Figure 3 Comparison of growth between an oxisol (left) and a Terra Preta soil (right) Photo Julie Major

Why trees don't sequester

Very often, tree planting is recommended to sequester carbon from the atmosphere. This is a misinterpretation of the role of plants in the carbon cycle. Biomass fails to permanently sequester carbon from the atmosphere for several reasons.

1. Plants constitute an open system that is in balance with the atmosphere. What is taken up will be released with some time delay. (Figure 4)
2. Newly planted biomass will sequester carbon maximally only at the middle of its development to maturation. (Figure 5, solid line). This means that, when you plant a forest for carbon sequestration, the rate of carbon sequestering will increase the first 40-50 years of their growth. After that, the rate will diminish until full growth, when respiration will equal their uptake of carbon.
3. At full growth, say 100 – 150 years after the establishment of the forest, the plants have stored carbon maximally (grey field in Figure 5). Any disturbance after this time will release carbon into the air again. So, you cannot harvest the forest, nor should you allow pest, disease or fire. This is a clearly unsustainable situation.

Thus, assuming that increased tree planting will counteract carbon dioxide contamination from fossil fuel burning is, to say the least, a short-sighted solution. Naturally, this is even truer when talking of annual plants, such as most agricultural crops.

However, a strategy to increase the dynamic plant cover will increase the amount of the carbon dioxide sequestered from the atmosphere. Some such strategies will be discussed below.

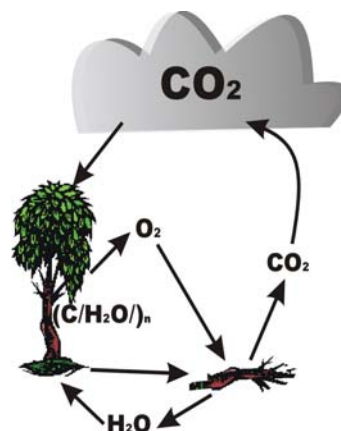


Figure 4 The plant carbon cycle is storage neutral, i.e. carbon will **only** accumulate in a growing crop.

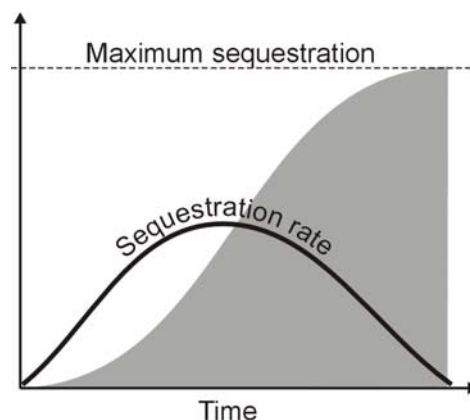


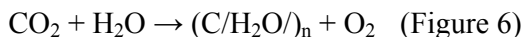
Figure 5 The rate of absorption (black line) is at maximum when the trees are half-grown. After maximum growth, the plants respire the same amount of carbon as they absorb (grey area). Any disturbance will return carbon to the atmosphere.

Carbon chemistry for dummies

In order to make the discussion intelligible I will make a short interlude to recapitulate the basics of carbon chemistry. Those who are familiar with this are advised to jump to the next section in order to avoid being annoyed by the incompleteness of the description.

Light and dark reactions

During photosynthesis, carbon dioxide and water are combined to carbohydrates and molecular oxygen, as in the well-known formula:



The available energy in sunlight is added to the low energy carbon dioxide and water molecules, to make carbohydrates (depicted as $(\text{C}/\text{H}_2\text{O})_n$) with higher energy content. The use of this captured energy is what life is about.

In fact, photosynthesis is *the only* ubiquitous way the atmosphere is deprived of carbon dioxide.

The primary products of photosynthesis are carbohydrates, such as simple sugars.

Subsequently, these are converted into more complex carbohydrates, such as compound sugars, starch, cellulose; and further into proteins and the rest of the plant metabolism. Of the common successors of the simple carbohydrates, cellulose is the most stable.

However, since it is a coveted energy source for many micro-organisms, it will soon be used up once the plant is dead. Only a minor part of the carbon pool exists as carbohydrates, since they are relatively unstable and readily oxidized into carbon dioxide (Figure 4 and Figure 7). Because of this instability, most of the cellulose produced will decompose within a century of its formation, whatever you do to protect it. A carbon sink worth its name has to keep the carbon away from the atmosphere for a *very* long time. Trying to increase biomass to counteract the increasing carbon dioxide level of the atmosphere is therefore in vain due to the relatively fast turnover of carbohydrates. (Figure 5)

During dark conditions (Figure 7), plants consume more carbohydrates than they produce. They extract the available energy in carbohydrates, decomposing them into carbon dioxide and water (Figure 7). By that, their net performance is similar to that of heterotrophic organisms, as animals or fungi.

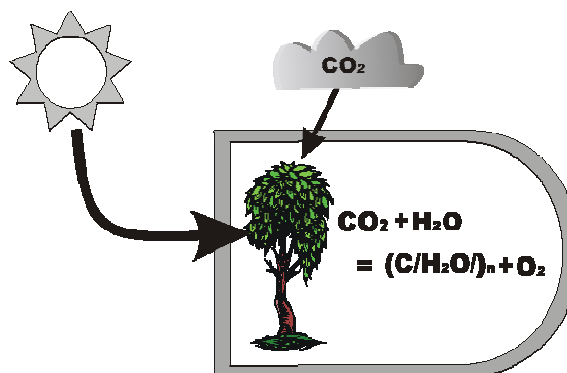


Figure 6 The *light* reaction of plants: Solar energy is captured into carbon dioxide and water and converted to carbohydrates and oxygen. This is the basis for life.

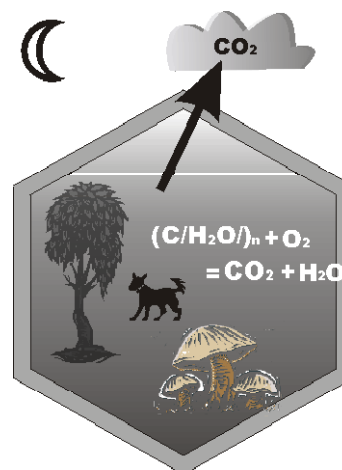


Figure 7 The *dark* reaction of plants is the same as in heterotrophic organisms, such as animals or fungi. Carbohydrates are consumed and converted into carbon dioxide and water.

Carbohydrate decomposition in environments with different amounts of oxygen

Whatever the environment, if possible, carbohydrates will decompose into other products with lower free energy. However, these products will be very different depending on the amount of oxygen available and three subsequent types of environment (anoxic, oligoxic and oxic) are succinctly described here.

1. The anoxic, or oxygen free, environment

In an oxygen free environment, as for example in deep sea sediments or in a biogas plant, micro-organisms will decompose carbohydrates to use their energy rich bonds. Since no oxygen is available in their environment, they will use the oxygen in the carbohydrates. The end products of this are, beside the common carbon dioxide and water, mostly simple hydrocarbons such as methane (CH_4), but higher hydrocarbons can also occur⁸. Methane is the most common petroleum gas fraction, strangely called 'natural gas'. By high pressure and heat in the deep rocks, higher molecular weight hydrocarbons, such as oil, tar and pit coal evolve. These carbon compounds are the source of our current carbon dioxide problems; burning petroleum is the same as burning ancient biomass, and the result is the same: increased carbon dioxide and water and the reduction of the global oxygen pool.

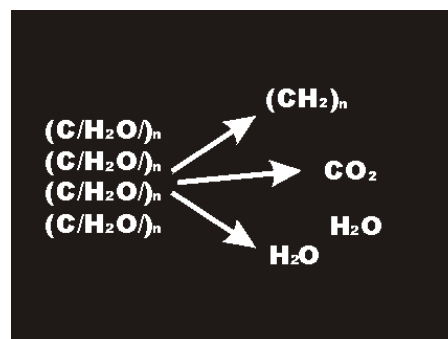


Figure 8 In oxygen free conditions, bacteria use the chemical energy in carbohydrates and convert them into hydrocarbons, water and carbon dioxide.

2. The hot, oligoxic environment

When plant biomass is kept hot ($300 - 600^\circ \text{C}$) with very little accessible oxygen, carbohydrates react chemically in two indistinctly separated steps. The first step is *pyrolysis*, during which tars, hydrogen gas and methane gas are released. They can be used for synthesis of other products, as biodiesel or fertilisers⁹. The main product of the pyrolysis of biomass is charcoal, theoretically up to 40 %, represented as $(\text{C}-\text{C}-\text{C}-\text{C}-\text{C})_n$ in the picture.

If the charcoal is heated further under restricted access to oxygen and water vapour, the *gasification* process takes over, i.e. the charcoal and water are transformed into a mix of carbon monoxide, hydrogen and carbon dioxide, (called *producer gas*, *syngas* or *wood gas*).

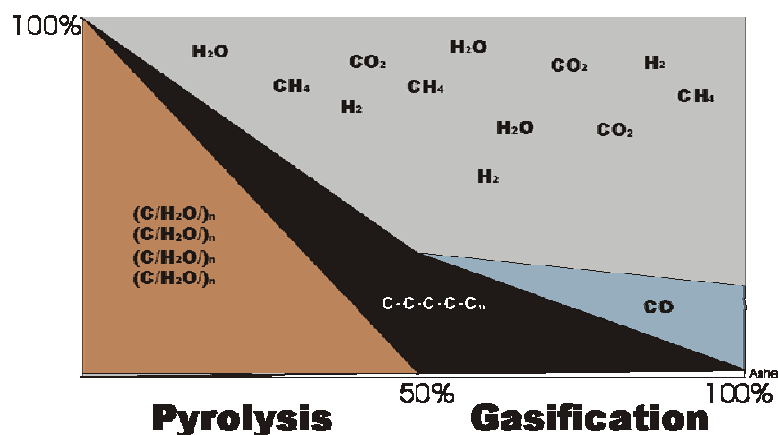


Figure 9 A summary diagram with a rough outline of the oligoxic processes. Typical for the *pyrolysis* phase is the formation of charcoal. In the *gasification* phase, charcoal is transformed into carbon monoxide and other gases that are reactive if taken into an oxygen-rich environment.

Carbon monoxide and hydrogen can be used as engine fuels, as well as raw material for industrial processes.

The pyrolysis phase and the gasification phase differ from each other only by temperature and time. Thus, it is rather easy to construct a charring and syngas production device that can be adjusted to produce either charcoal or syngas, or any combination thereof.

3. The oxic environment

In an environment where oxygen is abundant, as in an ordinary fire, an internal combustion engine or an animal or plant body, the end product of carbohydrate decomposition will be carbon dioxide and water¹⁰.

Understanding the decomposition processes explains why you can not store carbon dioxide as biomass for any length of time. Carbohydrates are simply too reactive. However, if the plant cover of a landscape is *permanently* enhanced with (perennial) plants, the standing crop of the plants represents an actual carbon dioxide sequestration. But as soon as it thins out, typical for senescence, this effect is lost. Aiming at carbon dioxide sequestration, one could imagine a landscape, previously bare (as an agricultural or urban landscape), planted with perennial plants that are harvested continuously when reaching mid-age (see Figure 5), and the harvested biomass is used for producing charcoal (see below).

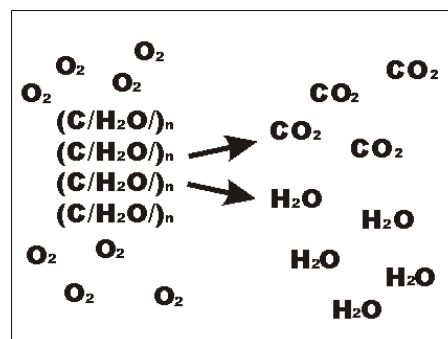


Figure 10 In an oxygen rich environment, carbohydrates will decompose into carbon dioxide and water. Biomass is therefore an unreliable carbon dioxide sequestering method.

Charcoal

In nature, carbon can exist in several oxidation steps, from the most oxidised forms, as CO_2 , to the most reduced, e.g. CH_4 . In pure form, as C, in diamond, coal or charcoal, carbon is neutral, i.e. neither reduced nor oxidised. This state is very resistant to spontaneous decomposition (well known in diamond and graphite, but also typical for charcoal). Charcoal is considered one of the most stable carbon pools due to its unique chemical characteristics and its associated resistance to biological decomposition. Estimates of the average residence time of charcoal in soil vary from some hundreds to several thousands of years¹¹.

Furthermore, as charcoal keeps a lot of the internal structure of the feedstock plants, it has a much more intricate structure than its relatives, such as graphite (laminar sheets) and diamond (crystalline). It is therefore often referred to as amorphous.

As a carbon sequestration method, depositing charcoal in the soil is therefore certainly the easiest method. This is what we learnt from the pre-Columbian Indians (Figure 2). Producing charcoal is an insight as old as the knowledge of making fire¹². It is certainly a low-tech method¹³, although it can be refined into a high-tech method utilising the by-products¹⁴. Sequestering carbon dioxide is not the only reason for burying charcoal in soils. Certainly, *carbon sequestering* was not the reason for the creation of the Terra Preta soils by the pre-Columbian Indians. Their main motivation may have been at least two-fold;

- 1) Cutting down a tropical rain-forest with a stone-axe is difficult work. Repeating it every five years would be overwhelming, which would be the case if they used the slash-and-burn method. Instead, they developed the slash-and-char method¹⁵ which means that they smothered the fire with grass and leaves to turn the biomass into charcoal. This charcoal, supplemented with further additions later on, came to constitute a large part of the soil in the tightly inhabited Amazonian areas in pre-Columbian time.

- 2) The charcoal enriched soil does not leach nutrients due to the large internal structure which allows efficient adsorption, as well as encouraging micro-life. If nutrients are added from the beginning, as animal or plant debris, and returned to the soil in the same rate as it is used (recycling!), the soil fertility will be maintained for hundreds of years. This practice gave rise to one of the most fertile soils on Earth¹⁶.

Due to its porosity and thus its large internal area, up to $1500 \text{ m}^2/\text{g}$ ¹⁷, charcoal has an excellent capacity to adsorb nutrients and organic material, and hence also works as a very good habitat and growth area for soil micro-organisms. Therefore, in any poor soil, such as excessively sandy, clayey or leaky soils, the addition of charcoal is a good way to improve it. The charcoal works as a 'sponge' for the nutrients, which due to the increased microbial biomass are accessible for the plants growing nearby. (Plants 'buy' nutrients from micro-organisms with sugars released from their roots). Charcoal also exerts significant effects on the decomposition of added litter. The increased amount of microbial biomass has also a positive effect of the growth of earthworm populations (which feed on micro-organisms), something that will further augment the productivity of the soil¹⁸.

In boreal forest ecosystems dominated by ericaceous dwarf shrubs, charcoal has also important beneficial effects. It is likely to provide a major contribution to the rejuvenating effects of wildfire on forest ecosystems.¹⁹

Charcoal has also been suggested as a potential tool for the remediation of contaminated soils and waters in modern urban and periurban areas.²⁰

Thus, far from being an inert remnant in the soil from ancient fires, charcoal is a highly valuable component, providing retention of nutrients as well as an increased micro-life and stabilisation of the chemical environment.

Do not put fresh charcoal into the soil!

However, if you add a lot of fresh charcoal to the soil, the previously existing fertility might temporarily *decrease*. This, and the length in time of this phase, depends of the properties of the charcoal. Its large inner surface makes a lot of nutrients and other soil substances adhere to it, making them temporarily unavailable for the plants until the charcoal is saturated.

Contrariwise, when the inner area of the charcoal is full of nutrients and soil micro-organisms, it will work as a sponge for nutrients, readily available to interact with the plant roots, keeping the nutrients away from leakage.

Therefore, the inner surface of the charcoal should be saturated with nutrients before or during its addition to the soil. This can be done by mixing the charcoal with compost, manure, urine, or nitrogen fixed by Leguminous plants before or during the addition to the soil²¹. This was done by the pre-Columbian

Indians when the original Terra Preta soils were created. *For the sake of differing from the freshly made ('active') charcoal, I call this nutrient saturated charcoal 'charged', i.e. charged with nutrients.*

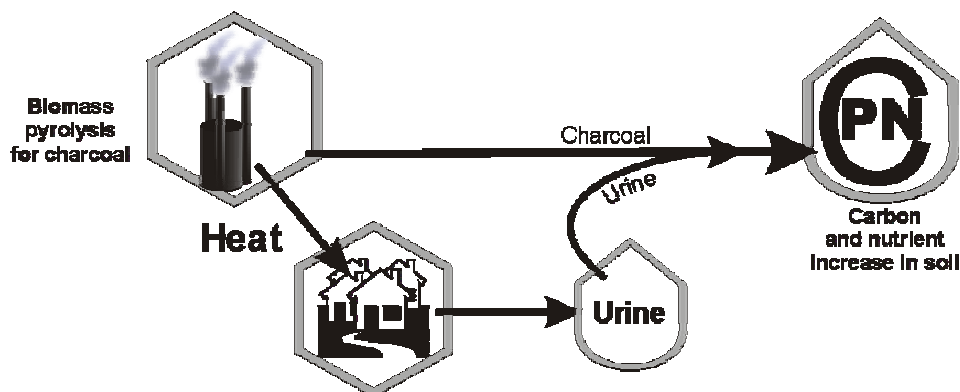


Figure 11 Adding human urine to the fresh charcoal would jointly alleviate the problems of freshly made carbon and urine storing.

In human settlements, the sewage system has been a problem since the start of urbanisation, and an increasing group of people work at replacing the present system with source separating toilets, producing urine and faeces in separate flows. The problem with this, however, is that the collected urine is highly volatile, and therefore, there are problems associated with its long-term storage before returning the nutrients to the fields. However, if the urine is used to 'saturate' the charcoal before it is fed to the soil, the problems with unstable urine and the problems emanating from the fresh charcoal might be alleviated simultaneously! (Figure 11) The *Eprida* process uses some of the hydrogen released in the pyrolysis process to capture nitrogen and carbon dioxide from the air, converting nitrogen to ammonium bicarbonate (NH_4HCO_3) fertilizer inside the pores of the charcoal²². This, too, is a method for the 'saturation' of the charcoal.

The pyrolysis: products and by-products

The only realistic way to actually reduce the carbon dioxide pool in the atmosphere is to use biomass to produce charcoal and bury the charcoal in the soil. This might be seen as a restriction of conduct, but it actually offers a multitude of potentialities that promote human innovation capacity and ingenuity. I will quickly go through the steps of the process in order to point out some of its potentialities.

1. Increased use of biomass

The start point for pyrolysis is access to plant biomass. Differing from biomass that is to be used for heating or building purposes, biomass that is to be used for charcoal production can be very diverse, from rice husks, straw or thin branches to logs, stumps or large lumps of wood. Also grain husks, straw or other harvest residues can be used.

- 1.1. If you are a **municipality**, standard pruning and shrubbery clearing produces a lot of bushes and branches that are expensive to dispose of. The thought of subsequent costs might even impede the planting of shrubs and trees in housing areas. On the other hand, if you can earn something from the process, as money and/or good-will, at the same time as you improve and restore the urban environment, why not? Working together with a nearby farmer or a specialized company, it will be easy for the municipality to convert the previously worthless stuff into charcoal. A plant on the mini- or meso-scale will easily pay off, even if only the previous garbage costs are accounted for. For a municipality, it is also simple to add the heat from the charring plant to a district heating system²³.
- 1.2. If you are a **farmer**, you could uncover the previously tunnelled streams and ditches in the landscape to let natural shrubs (as of *Alnus*, *Salix* and the like) grow in the vicinity of the streams to collect surplus nutrients. When large enough, these plants could be used for charring, the nutrients recovered and returned to the soil. This also goes for hedges. After harvest, just let the vegetation regrow. Any source of plant biomass that formerly was considered too disperse or too thin, can routinely be harvested using the normal farm equipment and used for charring, thus obtaining the advantages discussed below. As free side-effects, you can get such things as wind

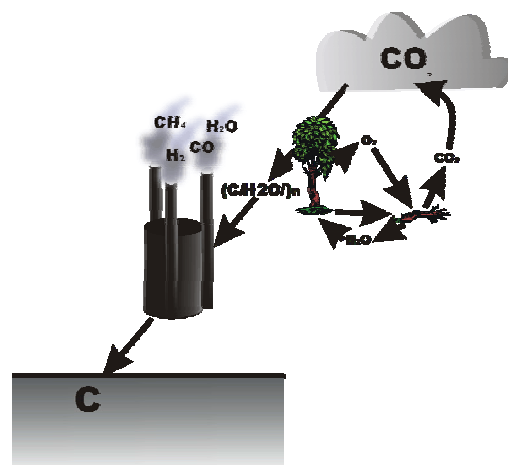


Figure 12 The long-term sequestering of carbon dioxide from the atmosphere involves three steps:
 1. Plant biomass production.
 2. Converting biomass to charcoal.
 3. Burying the charcoal in the soil.

breaks, increased biodiversity, nutrient retention, cleaner stream water and the like. Inventive farmers have already seen such possibilities²⁴.

- 1.3. If you are a **villager or house-owner**, the small scale of your garden should not deter you. A charring device need not to be larger than a standard oil drum, and can actually be built from a disused one²⁵. In a warm, sunny climate, you might build a solar driven continuous charring process with very small efforts²⁶. To routinely char the garbage from the garden instead of burning it will let you build up your personal Terra Preta.

The charcoal might be saturated in the bottom of your compost to avoid nutrient leakage, or you can easily make a simple device to saturate it with urine.

2. Converting biomass to charcoal

As was earlier pointed out; the knowledge of charcoal production is as old as the knowledge of making fire. The simplest way is to put sand on your fire. Makeshift kilns are still used all over the world, as charcoal is better to use in small fires than firewood. One type, the use of which is widespread, is the *pit kiln*. It consists of a lot of wood piled in an artificial pit, covered with sand, leaves, turf, or, more recent, with flattened oil drums which also are used to shield the sides of the kiln²⁷. The air intake is regulated through holes in the covering sand. It works reasonably well, can be used to convert large amounts of biomass into char but need a lot of people tending to it, and is rather inefficient. From kilns of this very primitive type²⁸, there is a continuum of sophistication to the most advanced industrial fluidized bed continuous processing plants²⁹ with a heat recovery system and complete re-use of the useful gaseous products. The general principle is that the more advanced types use increasingly complicated methods to hasten the process and make use of as many by-products as possible.

One can imagine the middle-scale device mentioned above equipped with heat-exchanger and an assortment of gas filters for district heating a local village, at the same time providing a work-place for the production of chemicals, raw material for plastics, using Fisher-Tropsch catalysis to convert carbon monoxide and hydrogen into biodiesel. The charcoal production from such a plant can be adjusted to the need for heat and other products. As long as a substantial part of the production goes to charcoal production for soil improvement and carbon dioxide sequestering, it has a positive impact on the global system.

Pit char system

1. Dig a large pit in the field.
 2. Collect the crop residues using a self-loading wagon (the kind used in Europe for loose hay or grass haylage, up to 72 m³ !)
 3. Fill the pit
 4. Insert steel tubes in the biomass
 5. Cover with earth
 6. Fire-up and blow some air through the tubes
 7. Stop blowing and wait (Use the volatiles if you can: You can fire them up in winter and use water tubes in the pit as heat exchangers to heat your buildings...)
 8. Cool down
 9. Spread the carbon in the fields to improve the CEC, cation exchange capacity, good for poor and sandy soils
 10. Cash-in 20 Euros per ton of CO₂ sequestered.
- (Philippe Raufast praufast@free.fr)

3. Charcoal burying

The third step in the carbon dioxide sequestering process is persuading the people standing there with the charcoal in their hands, a precious energy source, to bury it in the soil! Before turning to the hard facts, one must point out that it is not essential for the sake of it to *always* put *everything* into the soil. Firstly, any batch of newly produced charcoal consists of a diversity of sizes, from dust to lumps. If you feel greedy, you might well keep the lumps and use the scrap and dust for soil amendment. Secondly, during different times of the year, the local needs for charcoal may differ from what is available. If you have a temporary surplus of feedstock, as in harvest times, a larger part can be used for soil amendments than otherwise. Now, to more determining reasons for actually putting the charcoal into the soil:

3.1. Carbon sequestering for the ethics of it

Global warming is a fact. A lot of it is due to the fact that there is too much carbon dioxide in the atmosphere. Since the beginning of industrialization, the carbon dioxide content of the air has increased by about 45%. To reset the carbon dioxide content of the atmosphere to its pre-industrial level, you have to sequester about 9 metric tonnes per hectare (or: 0.9 kg/m²) into all agricultural soils over the world. Depending on the density of the soils and charcoal, this corresponds to about 30% carbon in the soil, which happens to be the percentage measured in the best Terra Preta soils studied in the Amazonian area³⁰.

So if you want to *do* something about global warming, however little, buy a sack of ready-made charcoal (of the pure type, not the mixture called ‘briquettes’) and bury it in your garden plot or the local park! It would be at least something³¹.

On a larger scale, see the suggestions on page 9.

3.2. Practical reasons: soil improvement

Leaving the ethics aside. Whether you have a poor, or reasonably good soil, adding charged charcoal is always a good idea. Of course, the worse the soil is from the beginning the more difference you will see. If the soil is very clayey, or very sandy, the added charcoal will work as a long-time organic amendment, making the clay easier to work and the sand less leaky, keeping its moisture better. The carbon will also increase the CEC, the cation exchange capacity of the soil³². CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from nutrient contamination.

Due to the structure of the charcoal, it works as a sponge for nutrients. Inside the charcoal, a society of micro-organisms the mykorrhiza, will establish, releasing nutrients at the same pace as they receive sugars from the roots of the plants, which in turn is dependent on the amount of sun and heat available to them. As a result, the nutrients will be released exactly when they are needed by the plants³³.

Tropical soils are often very prone to drought damage and nutrient leakage, which makes them hard to recover after flood or draught. Adding charcoal will improve their physical properties³⁴, charcoal with added nutrients from compost, manure and the like will improve them into a valuable farming soil³⁵. The differences between the oxisol (Figure 1) and the anthrosol Terra preta (Figure 2) have been discussed above.

3.3. New opportunities to bring in money: Fair carbon tax

As you have to pay money (tax and emission rights) to release carbon dioxide into the atmosphere, it should be fair to receive some of this money if you are able to sequester the same amount from the atmosphere. Such opportunities, and how they could be implemented are discussed below. N.b. that these amounts are not just some alms, but may constitute the majority of the income of a farmer.

Producing biomass for carbon sequestration

Only a part of the standing crop of biomass (aside from high-yielding annual crops as industrial hemp, discussed below) is available for harvesting each year. If your aim is to make biomass available for charcoal production, the first step is to increase the total biomass in the area.

In an agricultural area, a permanent change towards increased standing crop of biomass is rather easy to attain. Restoring the ditches from the ducted water streams would give some meters on each side for perennial plants that may be harvested every three or four years

without any special tillage measures. Intentional meandering of the streams would increase the crop area. Using *Salix* plantations, you may expect about 1 kg production dry weight m⁻² per year³⁶, or a harvest of about 30 metric tonnes dry weight per hectare per every four years, corresponding to a charcoal harvest of 2-2.5 tonnes per hectare per year. With ‘natural growth’, you may expect about 2/3 of that amount, but on the other side, you don’t have to pay so much attention to it. Growing industrial hemp may give a charcoal harvest of up to eight metric tonnes per hectare per year.

Furthermore, the ashes can be used as fertilizer on the fields, as the charcoal if you can charge it in one way or another. Biomass harvesting and charring can be done during winter, when other agricultural work does not need urgent attention.

Charcoal production from crop residues

Any reasonably dry crop residue, as straw, husks, nut shells, olive kernels, you name it, can be used as a raw material for charcoal production. In the case of straw, the annual production tends to be at least as large as the production of grain, why charring and crop production may use the same field. See for example the ‘pit char system’ outlined at page 10. Naturally, more advanced movable pyrolysis devices will easily be constructed and used.

New agricultural practice

Changing the agricultural system from aiming only at food production, to the additional aim of carbon sequestration involves the introduction of new crops and harvesting methods, as well as new views of the agricultural landscape. Shrub borders and open ditches with lush vegetation may no longer be seen as a nuisance to the rational farming system, but as an asset, not only for biodiversity, but also for the winter charring season.

Salix

As ‘energy forests’, short rotation growths (3-4 years) of the Salicaceae family, the *Salix* and *Populus* species are becoming a familiar sight in the agricultural landscape. The annual harvest is not *so* large, about 10 metric tonnes dry weight per year, but the plants are rather healthy and do not need so much tending and care. After the initial planting and some fertilizing, they just need to be harvested every fourth year and left to re-grow. However, it has been claimed that the growth of the ‘energy forest’ plants should be considered a way to counteract the global carbon dioxide increase. This is only right if they represent a *permanent biomass increase* in the agricultural landscape, actually, their standing crop average (including their root system). Nevertheless, if the plants are used for charring, not for burning, they might in any case work well as a mean towards long-term carbon sequestration.

The industrial hemp

Hemp (*Cannabis sativa*) has a theoretical maximum production in sub-boreal areas of up to 70 ton dry weight³⁷ per hectare. It has been abandoned for agricultural use due to the content of THC (delta-9 tetrahydrocannabinol), in the traditional cannabis drug (marihuana) associated with hemp. However, industrial hemp has very low levels of THC, lower than 0.2%, which is



Figure 13 Hemp production is surprisingly good even as far north as in Sweden. Here, a production of 25 tonnes dry weight per hectare, with an average height of four meters. The man on the picture is 180 cm
Photo: Rune Ekman, [Bionic](#)

the current legal level for cultivation in Europe. The drug-hemp normally contains 3-20%. Due to its origin in mountain districts, it grows surprisingly well in dry and cold conditions. Harvests may be as large as 19 metric tonnes dry weight as far north as in the Jämtland area of Sweden. Further south in Sweden, harvests as large as 32 metric tonnes dw/ha per year have been measured in test plantings. Seen as a carbon sequester, the hemp might give as much as up to 13 tonnes of charcoal per hectare annually, which would outdo the *Salix* plantations about three times.³⁸

Increasing the carbon content of the soil

The easiest and most reliable way to increase the amount of carbon in the soil is to add charcoal, preferably charged with nutrients to avoid a 'nutrient depletion shock' that would be the case if freshly made (= adsorption active) charcoal is added to the soil. Naturally, there are other ways to increase the carbon content of the soil, as different cultivation methods, frequent clover-rich leys, alfalfa-growing, organic green-manuring or mulching methods, frequent ploughing-in of straw or haulm, you name it. However, the latter methods all add organic matter as carbohydrates and other rather easily metabolized forms, which often are very good for soil health and structure, but less good if the aim is long term reduction of the carbon dioxide content in the air.

Nevertheless, any increase of the carbon content of the soil should be counted in a struggle for reducing the carbon dioxide of the air.

Reliable number of the carbon content of the soil are often very slow and expensive to attain, but new methods using the Ensemble Kalman Filter (EnKF)³⁹, has been developed by prof James D. Jones and associates on Gainesville University, Florida⁴⁰. The approach combines computer models with soil sampling to estimate soil carbon levels with high accuracy and at low cost. The method is originally developed for use in developing countries, but it is universally applicable.

For the 'soil manager' (farmer or other), or the official, working for the '**Carbon sequestration fund**' (see below), this would be a good way to document the carbon increase in the soil, so the soil manager can go to the fund and claim money for the effective sequestration.

An excursion into economics: *Internalizing an externality; Rights and taxes*

Economy is fundamentally about human interactions. Because of this, there is a basic inability to incorporate external factors as climate, ecological relationships, natural resources, environmental services, pollution and the like into economic models. In the models, these are considered 'externalities', i.e. things that are not considered in the economic models. However, sometimes, the system proves to be incapable of handling vital facts due to the shortcomings of the economic models, as in the case of global warming.

To cope with such problems, economists use a trick called 'internalizing'. This allows them to make the economic model behave as if the problem was inside the model. To cope with the carbon dioxide problem, economists have invented two tricks; 'emission rights trade' and 'carbon dioxide tax'.

*If the aim is to avoid emissions of carbon dioxide, the **emission rights trading** is a failure, as it does not aim at diminishing the emissions, just deciding whom shall create them.¹ This does*

¹ Consider *child abuse* as the externality to be coped with. Then you allow everybody to strike kids, e.g. 10 times. Since some people do not like hitting kids, or have found other ways to communicate with them, they can sell their 'hitting rights' to other people, more prone to hit kids. By this, the total amount of child abuse would not diminish, but you have created a new market.

not affect the size of the total emission cloud; it only starts a new type of trade⁴¹. There is an underlying notion that the price of the emission rights will increase, making people more and more reluctant to make their emissions, thus decreasing the total emissions. However, the last year this has not been the case⁴².

The **carbon dioxide tax** is used as another measure to diminish the carbon dioxide emissions. For every tonne of carbon dioxide emissions, you have to pay a certain (negotiable) amount of money. The risk with this conduct is two-fold: 1) If you inherently make a lot of emissions, and hence will be due to pay a lot of tax, you can claim that the tax will hurt your company, thus making you less able to hire workers and so on. Therefore, you can maintain that you should pay less tax. Hence, a lot of large emitters such as airplane companies, farmers, greenhouse owners, shipping companies, mining companies, fishermen and district heating companies will receive a substantial reduction (about 80%) of the carbon dioxide taxation. However, end-users, such as households, are often subjected to full tax payment. 2) If you are a company, the taxation of carbon dioxide emissions associated with your product, tends to be added to other production costs, and thus added to the price of your products; i.e. the cost will be passed on to the consumers.

The increased cost is in both cases passed on to the consumers, in both cases, adding to the total inflation pressure and to the general bureaucracy, but only marginally affects the total carbon dioxide emissions. However, by selling emission rights and taxing emissions, the governments may claim that they really are doing something about carbon dioxide emissions. Thus, carbon emission trading and tax has a propaganda value that should not be underestimated.

An excursion into politics: The carbon sequestration fund.

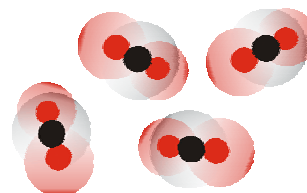
Earlier in this paper, I have treaded the fairly solid ground of science, but now I have to stagger into the slippery area of politics. Doing this, I try to collect facts as I understand them, and make a suggestion that I find feasible.

- Political fact 1: Over the world, although at different rates in different countries, and certainly not in all countries, people are paying a tax for the emission of carbon dioxide.
- Political fact 2: Following the Kyoto conference, there is an international trade on emission rights⁴³.
- Political fact 3: Facing the environmental disasters of the last years and verging on climate change, there is an increasing international willingness to put money into counteracting measures.

Suggestion: Externalizing an internality; Making taxes and rights work in real life

All carbon dioxide molecules are similar. Whether it is a breath from a dying person or emissions from luxury air liners, the molecules do the same injury to the planet's climate system. However, below a certain level, carbon dioxide is actually useful to the planet, to keep the temperature at a certain level⁴⁴. However, the carbon dioxide level is currently too high by at least by 25-

30%, which is one of the reasons for the current situation of global warming. This means that to avoid disaster (A in Figure 14), it is imperative for mankind to reduce the carbon dioxide level. Only a combination of ignorance, neglect and lack of responsibility can allow room for any discussion on whether a business should bear less responsibility (= needs to pay less) if the business' activities create large emissions (as for airplane companies, farmers, greenhouse



owners, shipping and transportation companies, mining companies, fishermen and district heating companies), thus needing a substantial reduction in the carbon dioxide taxation . Facing the crisis, everybody should at least take responsibility according to their share of the problem. If your activities create emissions, you should make an (economic?) effort proportional to the emission, e.g. pay a carbon emission tax. Furthermore, in our current economic system, to avoid *increase* of the carbon dioxide level you should buy a carbon dioxide emission right – *from someone who has sequestered the same amount as that which you produce*.

Today, the actual figure of the taxation is heavily negotiated, varying from € 384 per tonne on space heating oil without tax reduction in Sweden (€ 77 if you use much and therefore need a smaller tax), to about € 80 for space heating in Denmark, and about € 2 for heavy industrial processes.

Assumption

Therefore, because of the wide variety in taxation rates, it seems impossible to pick a number that could be described as a ‘general’ number, which is why I just choose numbers **for the sake of discussion**. These numbers are: **€ 25 per metric tonne carbon dioxide emitted and € 20 for the emission right of one metric tonne of carbon dioxide**.

To emit one metric tonne of carbon dioxide, then, Mr (or Mrs) M. Ission (!) has to pay the tax *and* have an emission right. The total *fixed* cost would then be € 45 per metric tonne of carbon dioxide.

These figures will naturally be a source of immense debate, but remember, *all* carbon dioxide molecules over a certain level (say; pre-industrial) are harmful to *all* of us, regardless of wealth or need, and; all negotiation could only be between people, not between the human beings and the rest of Nature, which is their support system for survival.

Assume you keep the familiar system of carbon emission trading and emission tax but refine the system, adding to it the knowledge of charcoal as a working carbon dioxide sequestering system. You could add the following rules:

1. *The carbon dioxide emission approval can only be sold by somebody who has sequestered a corresponding amount of charcoal⁴⁵.*
2. *An amount proportional to the carbon dioxide emission tax should be paid to the person sequestering carbon dioxide as charcoal.*
3. *A (preferably worldwide) fund, assigned for the prevention of global warming should be instituted that collects and administers the emission rights payments and the carbon dioxide taxes, as well as what can be collected from different nations, assigned for the prevention of global warming. This fund should also pay sequesters, and manage the trade on emission approvals.*

A Global Carbon Sequestering Fund

In order to avoid the mess that might result from the release of a trade according to the points above, a fund, preferably global, should be instituted. Not alleging any further similarities, it might have the same construction as the World Bank, the World Trade Institute or any similar body. Naturally, it needs to have a multitude of local branches. Look upon it as a bank with income from the brokerage of the transactions. It gathers the money from the countries collecting the taxes, and the payment from those who want to make emissions. Also, some or all of the funds negotiated for preventing global warming could be managed by this international body. Other greenhouse gases could naturally also be handled by this fund, as other allocations that might *decrease* carbon emissions (i.e. not just only diminish the increase).

Already the awareness of carbon dioxide sequestration as charcoal, without an international body regulating the trade, might lead to severe inhumane effects². Hiring poor people to bury carbon for below cost price is no better than any other form of oppression used to take control of other peoples' natural resources. Furthermore, a free trade on emission approvals (n.b. based on sequestration) will only stop the increase of the current emissions (B in Figure 14), *not* decrease the concentration of atmospheric carbon dioxide to a level where there are no further risks. Such a decrease (C in Figure 14) can only be attained by the additional introduction of a tax on carbon dioxide emissions.

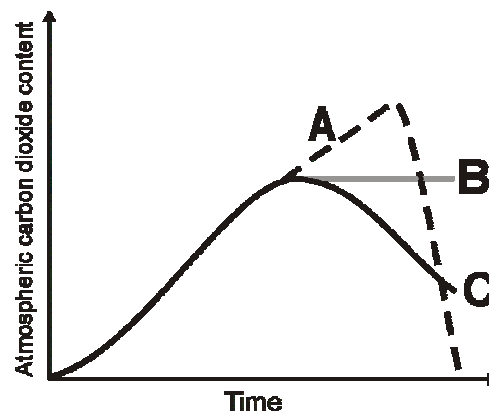


Figure 14 Effects of economic options on carbon dioxide level:

A) No measures. B) Trade on emission approvals. C) B plus tax on emissions.

Sequestration in practice

As a private person, or one having a company aiming at carbon sequestering, having sequestered a certain amount of carbon, you contact your 'local carbon dioxide sequestering official', who measures the amount (see above). The official gives you a paper, indicating the sequestered amount. Then, you go to the local branch of the GCSF, present your paper, choose if you want to sell your achieved emission approvals together with your 'negative carbon tax', and receive the money.

By that, a company or person (C. Quester!), which produces one metric tonne of charcoal and deposits it in the soil, would be paid 20 Euros for the carbon sequestering rights and 25 Euros for the 'negative' emission tax by the fund. Added to that is the value of improved soil, increased future harvests, heat, raw material for chemical industry and sewage/urine purification. If the total carbon-catching income is more than € 750 per hectare, it would be higher than a good harvest (8,000 kg) of wheat! It seems that the breaking point lies at 4-5 metric tonnes of charcoal per hectare, an amount rather easy to attain, certainly with less investment in time and machinery than the wheat.⁵⁴

Table 1 Income per hectare for charcoal at different sequestering levels, with an assumed tax for carbon dioxide emissions of € 25 and a price for emission rights of € 20.

	€ per metric tonne		€ income, Supposed harvest: Ton C / hectare				
	CO ₂	C	1	2	3	4	5
'Negative' tax	25	92	92	183	275	367	458
Emission rights	20	73	73	147	220	293	367
Total	45	165	165	330	495	660	825

² Just imagine about what might follow an understanding of charcoal as a universal sequestering method; a large oil company (led by Mrs. Ruth Less) could buy Burkina Faso to cut down the rain forests in Nigeria for making charcoal for burying in the soils of Burkina Faso, uncharged, creating a deprivation of nutrients. Then, her company could claim that they have no net emissions of carbon dioxide, thus winning a lot of good-will resulting in greater market shares ("Fight Global Warming, Buy Our Gasoline"). This conduct, spread over the world might level out the carbon dioxide emissions to the current level, but will never decrease it below this (B in Figure 14), which is urgent.

Conclusions: A system structure for carbon dioxide reduction

Figure 15, summarizes the content of this paper. In essence it describes the carbon dioxide sequestration that almost everybody can achieve by transferring plant biomass into charcoal, and that this transformation has a lot of benign side-effects;

- 1) Realizing that plants are most active in carbon dioxide sequestering when they are mid-growth will increase the willingness to raise a large diversity of plants that were earlier considered worthless, which in turn will improve the diversity of the landscape. Also, new crops, as the industrial hemp, can be added to the agricultural practices.
- 2) The charring process in itself opens for new activities.
 - a) The pyrolysis gases are useful in a number of chemical processes, such as the creation of bio-diesel using the relatively well understood Fischer-Tropsch catalysis process. Also, hydrogen and methane are well known for their versatility in chemical processes.
 - b) The heat produced during the pyrolysis process may well be used for space-heating or to facilitate the chemical processes mentioned above.
- 3) The need for charging the fresh charcoal before adding it to the soil might change the view of humanure as a waste product that should only be disposed of as soon as possible. Also, farmyard manure might be used in this respect, as well as some chemical fertilizers, the negative side-effects of which may be alleviated.

The need to charge the charcoal previous to burying, coupled with the need to make an intelligent use of human excrements may increase the pace of change from the current inefficient wastewater system into a modern one, where the different components are not mixed.
- 4) Adding the charged charcoal to the soil has many well-documented side-effects on fertility, reduction of leakage and crop production in general. The half-millennium old *Terra preta do Indio* anthrosols of the Amazonas and various other locations are good exponents for that.
- 5) The creation of a global Carbon Sequestration Fund, honestly applied, might create a situation where it is *good business* for farmers and existing or newly started firms to sequester carbon, as well as to create industry clusters of pyrolysis – gasification – chemical manufacturing, providing both charcoal for sequestration and chemical by-products as plastics, fertilizers⁴⁶ and energy carriers such as biodiesel and charcoal. Of course, in its immature state, it may lead to over-exploitation of biomass, but as soon as the need for growing new biomass for sequestration purposes is realized, the situation would stabilize. The growth of perennial crops for combined agricultural – sequestering purposes, such as agroforestry, would be encouraged.

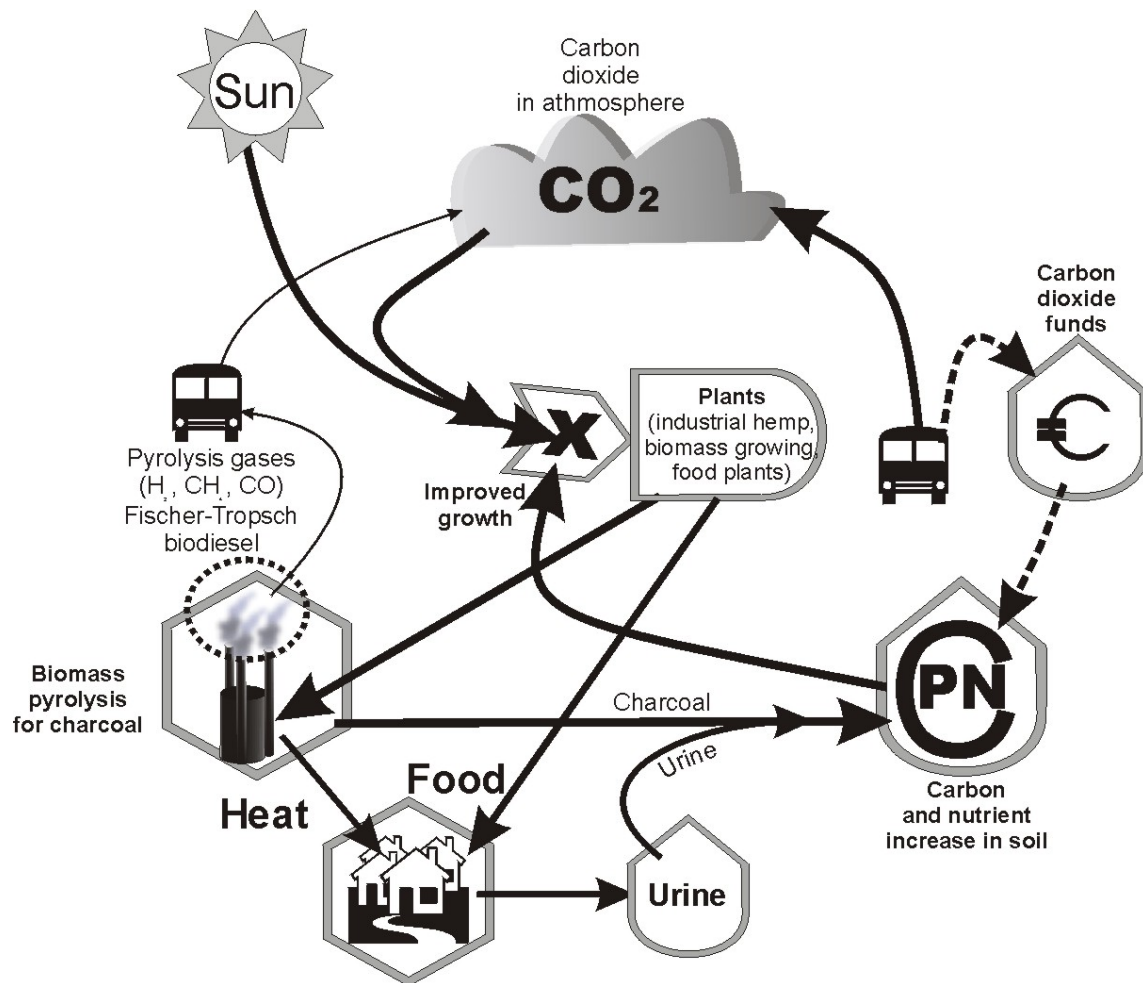


Figure 15 The system structure for the incentives of a global carbon dioxide sequestration

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End notes:

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- ¹ <http://www.athenapub.com/orellan1.htm>
- ² Meggers, B., 1971
- ³ The pictures of the oxisol and the terra preta anthrosol are from Dr Bruno Glaser's work on Terra Preta at http://www.geo.uni-bayreuth.de/bodenkunde/terra_preta/
- ⁴ http://www.geo.uni-bayreuth.de/bodenkunde/terra_preta/
- ⁵ This type of slash and burn should not be confused with the traditional, sophisticated, older type with a sparse population returning to a previously burnt area first after 100 years or more.
- ⁶ Steiner & al. 2004.
- ⁷ Mann, C., 2002
- ⁸ Björkqvist, S. & al. 1998
- ⁹ Day, D. & al. 2004
- ¹⁰ N.b. that new water is produced during this process and those above. The tale that we have the same water on Earth today as in primeval times is thus a myth!
- ¹¹ Krull & al. 2006
- ¹² Lehmann & al. 2006
- ¹³ See e.g. Hollingdale & al. (1999) and Fao Forestry Paper 41 (1987)
- ¹⁴ E.g. the Fischer-Tropsch method for biodiesel production, http://en.wikipedia.org/wiki/Fischer-Tropsch_process
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- ²⁰ de Leij & al. 2006
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- ²³ Breag & al. 2005
- ²⁴ <http://www.bidstrup.com/carbon.htm>
- ²⁵ <http://www.allotmentforestry.com/fact/Charcoal.htm> , <http://www.clt.astate.edu/elind/charcoalvalentine.htm>
- ²⁶ <http://www.bidstrup.com/carbon.htm>
- ²⁷ Hollingdale & al, 1999
- ²⁸ Fao Forestry Paper 41 (1987)
- ²⁹ E.g. <http://www.patentstorm.us/patents/5435983-fulltext.html>
- ³⁰ A fairly good calculation on this can be found at <http://www.bidstrup.com/carbon.htm> . Of course you are welcome to refine the figures if you are inclined to that.
- ³¹ Oberstiener & al. 2002
- ³² Liang & al. 2006
- ³³ See e.g. <http://ic.ucsc.edu/~wxcheng/wewu/links.html> for more about this.
- ³⁴ Glaser & al. 2002
- ³⁵ Lehmann & al. 2003a; 2003b
- ³⁶ Nordh & Verwijst, 2004
- ³⁷ Rune Ekman, Bionic, estimate from optimisation experiments in the Biotron, the climate chamber of the Swedish Agricultural University at Alnarp, personal communication 2006
- ³⁸ Deeley, 2000
- ³⁹ <http://enkf.nersc.no/>
- ⁴⁰ Jones & al 2005
- ⁴¹ Godoy, Julio
- ⁴² This can be seen at <http://www.pointcarbon.com/index.php>. Possible explanation to that: if the notion is that 'buying emission rights' is in some way associated with bad-will, the market will fail. Today, at mid-February 2007, the emission rights are worth less than one €, a decrease of about 30 € from the beginning of November 2006.
- ⁴³ <http://www.pointcarbon.com/>
- ⁴⁴ Sagan and Chyba; 1997
- ⁴⁵ i.e. 0.27 tonne of charcoal for 1 tonne carbon dioxide, or 3.67 tonnes of carbon dioxide for 1 tonne of charcoal
- ⁴⁶ Lee and Li; 2003